Center for Independent Experts Review for the Recruitment Processes Alliance Research in the Southeastern Bering Sea

A REPORT BY THE REVIEWER DR. PAUL G. FERNANDES

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ABERDEEN, SCOTLAND, UK

Contents

1 Executive summary

1. The Recruitment Processes Alliance (RPA) is a collaboration among the science programs of the National Marine Fisheries Service (NMFS) within the Alaska Fisheries Science Center (AFSC) and other offices. The goal of the RPA is to provide a mechanistic understanding of the recruitment of walleye pollock, Pacific cod, arrowtooth flounder, Chinook salmon and chum salmon, focusing on factors influencing the first year of ocean life in the Eastern Bering Sea. This document is an independent peer review of the RPA's recruitment processes applied research. The review was based on a visit to the AFSC from 21 to 24 July 2015 involving presentations given by RPA staff and an examination of literature provided.
2. An extensive body of peer reviewed literature was provided which has been produced by forerunners to the RPA over several years. This literature converges on the modified Oscillating Control Hypothesis (OCH) to explain variability in the recruitment of walleye pollock, the species of most interest given its valuable fishery. The OCH suggests that recruitment is favored by cooler periods, which favor lipid-rich plankton as food for both age-0 pollock [enabling them to overwinter] and for the adult fish [reducing cannibalism]. This hypothesis, and a wealth of other published work, has arisen from an impressive series of process studies, modelling work, and an extensive monitoring program of oceanographic moorings and two ecosystem surveys in spring and late summer.
3. The spring ecosystem survey design should be modified to reduce sample intensity in the along-shelf direction (maintaining sample density in the across-shelf direction). Studies should be carried out to confirm that this would have little effect on estimates of the quantities of interest, which is likely due to the patchy distribution of the targets of interest. The time saved should then be given to expanding the survey area to include a larger core, and adaptive extensions to cater for wider distributions in years of high abundance.
4. The late summer ecosystem survey (BASIS) should be changed to an acoustic survey to estimate age-0 pollock and other species, not an oblique trawl survey as proposed. Ecosystem sampling should continue and an index of euphausiid abundance should also be provided. Options are suggested for this change, but include carrying out a combined surface trawl survey for salmon at sea along with the acoustic survey. This would also deliver an annual leading index of Chinook salmon to inform an annual bycatch cap. The latter would justify requesting the pollock fishing industry to part-fund the survey by providing a fishing vessel charter. Discussions with a fishing industry representative suggested that this indicator would be beneficial enough to the industry as to merit this part-funding.
5. The NPZD-FEAST and EwE ecosystem models need to be refined and developed to enable multi-model ensemble approaches. Some consideration should be given to closing the stock recruitment loop in the NPZD-FEAST model by incorporating fish egg production and mortality. The high secondary peak in production in the NPZD-FEAST model needs to be verified. Acquiring additional cost effective empirical data (e.g. from ships of opportunity as per PICES CPR) should be considered to get a more synoptic view of the plankton cycle.
6. The role of ice-algae should be evaluated. These may be the ultimate source of lipids for the overwintering pollock and given the likely changes in sea ice extent induced by climate change, may have significant impacts on the ecosystem.
7. Better internal and international communication is encouraged, particularly with other stock assessors (engagement with the pollock assessment team is excellent), and AFSC's acoustics group (MACE). MACE should be resourced to provide analytical support to the RPA.
8. The RPA, with its well-integrated disciplines of oceanography, plankton ecology, young fish ecology and ecosystem modelling, is to be highly commended. There is no better

integrated program in the world aiming to resolve the age old question of variability in fish recruitment. Support for the RPA and its monitoring programs should be continued.

2 Background

The Recruitment Processes Alliance (RPA) is a collaboration among the science programs of the National Marine Fisheries Service (NMFS) within the Alaska Fisheries Science Center (AFSC) and across-line offices in the Office of Oceanic and Atmospheric Research (OAR) and the Pacific Marine Environmental Laboratory (PMEL). It brings together six fisheries programs working towards a common goal. These programs are the Ecosystems and Fisheries—Oceanography Coordinated Investigations (EcoFOCI) a joint program composed of PMEL and Recruitment Processes at AFSC; Ecosystem Monitoring and Assessment (EMA); Resource Energetics and Coastal Engineering (RECA); Resource Ecology and Ecosystem Modeling (REEM); and Status of Stocks and Assessment (SSA). The goal is to provide a mechanistic understanding of the factors that influence the recruitment of walleye pollock, Pacific cod, arrowtooth flounder, Chinook salmon and chum salmon, focusing on factors influencing the first year of ocean life in the Eastern Bering Sea (Figure 1). To accomplish this, seasonal (spring, summer, autumn) field surveys and process-oriented research are conducted to inform single-species, multi-species, and biophysical ecosystem models. Survey methods employ gridded survey designs with net samples and selected use of acoustics to collect target species, with concurrent oceanographic and environmental sampling to estimate biological and physical oceanographic structuring forces.

The Recruitment Processes Alliance (RPA) underwent an independent peer review of its recruitment processes applied research in the eastern Bering Sea from July 21 to July 24 2015. The independent review was conducted by the Center for Independent Experts (CIE) and examined methodology, data collection and analyses, and products from seasonal (spring, summer, autumn) field surveys and process-oriented research. This report details the individual views of one of the four reviewers, Dr. Paul G. Fernandes (see Appendix 3 for contact details, and for details of the other three reviewers). The report, as stipulated in the statement of work (Appendix 2), includes a description of the reviewer's role, a summary of findings for each Term of Reference (TOR), and conclusions and recommendations in accordance with the TOR. A full list of references, including those provided as background material, and those cited in this report, appears in Appendix 1.

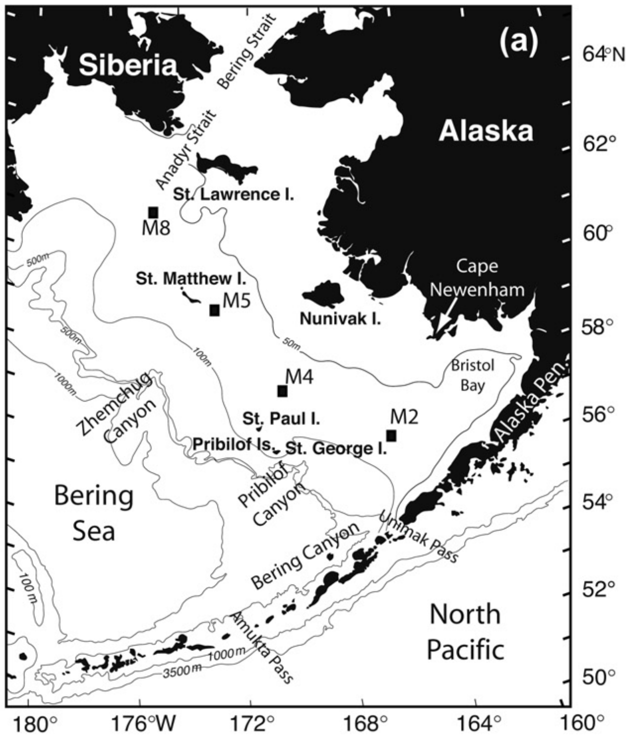

Figure 1. Map of the Eastern Bering Sea (EBS) indicating several locations of interest to the review. Reproduced from Stabeno et al. (2010).

3 Description of the Individual Reviewer's Role in the Review Activities

The reviewer, Dr Paul G Fernandes, is a fisheries scientist at the University of Aberdeen in Scotland UK. Dr Fernandes has a BSc in Marine Biology and a PhD in Marine Ecology from Liverpool University's Port Erin Marine Laboratory. He worked overseas in Bolivia on the artisanal fisheries of Lake Titicaca and in the Republic of Ireland, before embarking on a 17-year stint at the Marine Laboratory in Aberdeen, Scotland (now Marine Scotland Science). Initially, he worked on fisheries surveys (acoustics and trawl), then on fish stock assessment, and latterly he managed over 20 scientists in the Sea Fisheries group; this group was responsible for the assessment of Scotland's internationally managed fish stocks. He took up his current position as reader in Fisheries Science at the University of Aberdeen in July 2011 partly funded by the Marine Alliance for Science and Technology Scotland (MASTS). He has a small (8) research group, FEAST (Fisheries Ecosystems and Advanced Survey Technologies), working on topics such as ecosystem modelling, acoustic surveys (active and passive), trawl surveys, visual surveys and stock assessments. He also convenes the MASTS Fisheries Forum, which pools all of Scotland's expertise in marine fisheries across academic, government and industry sectors.

Dr Fernandes role in the review activities was specified according to matching experience and expertise in: (1) recruitment processes surveys and design including fisheries-oceanographic plankton and trawl survey design, operation, sampling and analysis; (2) field methods, including acoustics for process studies, and spatial sampling and analysis of distribution and abundance of young fish; and (3) experience in Ecosystem Based Fishery management and/or Integrated Ecosystem Assessment.

4 Summary of Findings for each ToR

4.1 TOR 1. Review of materials.

Review background materials and documents that detail the ecosystem and fishery survey design and methods, and data analysis methods and results for: a) Joint walleye pollock, Pacific cod, and arrowtooth flounder surveys; b) Chinook salmon and chum salmon survey; and c) Joint bio-physical oceanographic survey component (ecosystem).

A number of peer-reviewed manuscripts, as well as manuscripts in press or in preparation, were provided for the review (see bibliography in Appendix 1). The reviewer also prepared by reading a review of the walleye pollock fishery in the Bering Sea (Bailey 2013). Entitled "The billion dollar fish: The Untold Story of Alaskan Pollock" the book is an account of the development of the fishery, from the post-war boom years dominated by Japan and the Soviet Union to the gradual "Americanisation": where Norwegian-American crabbers switched their fishing methods and, aided by changes in international marine legislation, developed some of the largest fishing corporations in the world on the back of a massive resource. Despite the author's scientific credentials, the scientific content is limited: this is largely because it was not written for a scientific audience, but also, as pointed out, until the 1970's, there was barely a single scientific article [written in English] on walleye pollock. There has been a wealth of literature since the aforementioned "Americanisation" of the fishery. In addition to the commercial interest of what has been, at times, the biggest and most valuable fishery in the world (Ianelli 2005), there is an increasing interest in the ecological role of pollock given their status as prey for many important marine mammals and seabirds (Sigler et al. 2012).
Much of the scientific work on walleye pollock has focused on recruitment and a series of of recent papers relevant to the topic, and this review, were provided (see Appendix I). Two key references provide overviews that are pertinent. Duffy-Anderson et al. (2015) review the state of ecological knowledge relating to the critical first year of walleye pollock, identify gaps in knowledge and make recommendations for future research. They summarize six hypotheses to explain the significant recruitment variability in the species: 1) The Transport Cannibalism Hypothesis, whereby recruitment is enhanced by juveniles being transported away from the adult habitat in warm years; 2) The Recruitment Routes Hypothesis, whereby eggs are transported to areas that favor good feeding and growth and hence enhanced recruitment; 3) the Production-Competition Hypothesis whereby recruitment is enhanced by strong storm activity in warm summers (enhancing primary productivity and reducing competition for food); 4) the Oscillating Control Hypothesis (OCH), whereby the ecosystem alternates between cold phases with bottom-up control and warm phases with top-down control, where recruitment is favored by the latter. Subsequent empirical evidence (good recruitment in the cold years 2006-2009) prompted modification of the OCH, acknowledging that although warm years favor larger numbers of age 0 fish in the spring and summer, cold years are more favorable for survival to age-1due to the presence of lipid-rich copepods in the autumn (zooplankton abundance and energy density of zooplankton prey (Siddon et al. 2013); as well as oceanographic properties such as bottom water temperatures (Coyle et al. 2011). The systematic design is, therefore, entirely appropriate to estimate relative abundances, distributions, biomasses and to determine biological & physical properties as precisely as possible.

Initial surveys (prior to 2012) were process orientated and so the areas covered targeted specific species and/or stages (e.g. Figure 3b). The regular grid surveyed initially (Figure 3a) was expanded in 2012 (Figure 3c) to cover a larger area inclusive of more pollock and Pacific cod spawning areas in the Pribilof and Unimak islands. The latter design includes additional stations beyond the limits of the regular survey area which are given lower priority. Although the full northern extent of the spawning range of walleye pollock may not be always covered - e.g. Zhemchug Canyon (see Figure 1) has been reported as being important for spawning (Stepanenko and Gritsay 2014) - spawning in the north-western areas occurs later in the summer (Hinckley 1987), so the area coverage is probably appropriate for the time of year. However, given the variable nature of recruitment (Bacheler et al. 2010), some form of adaptive coverage might be appropriate to capture more extensive spawning events, whilst maintaining the core area delineated in Figure 3c (see recommendations in Section 6).

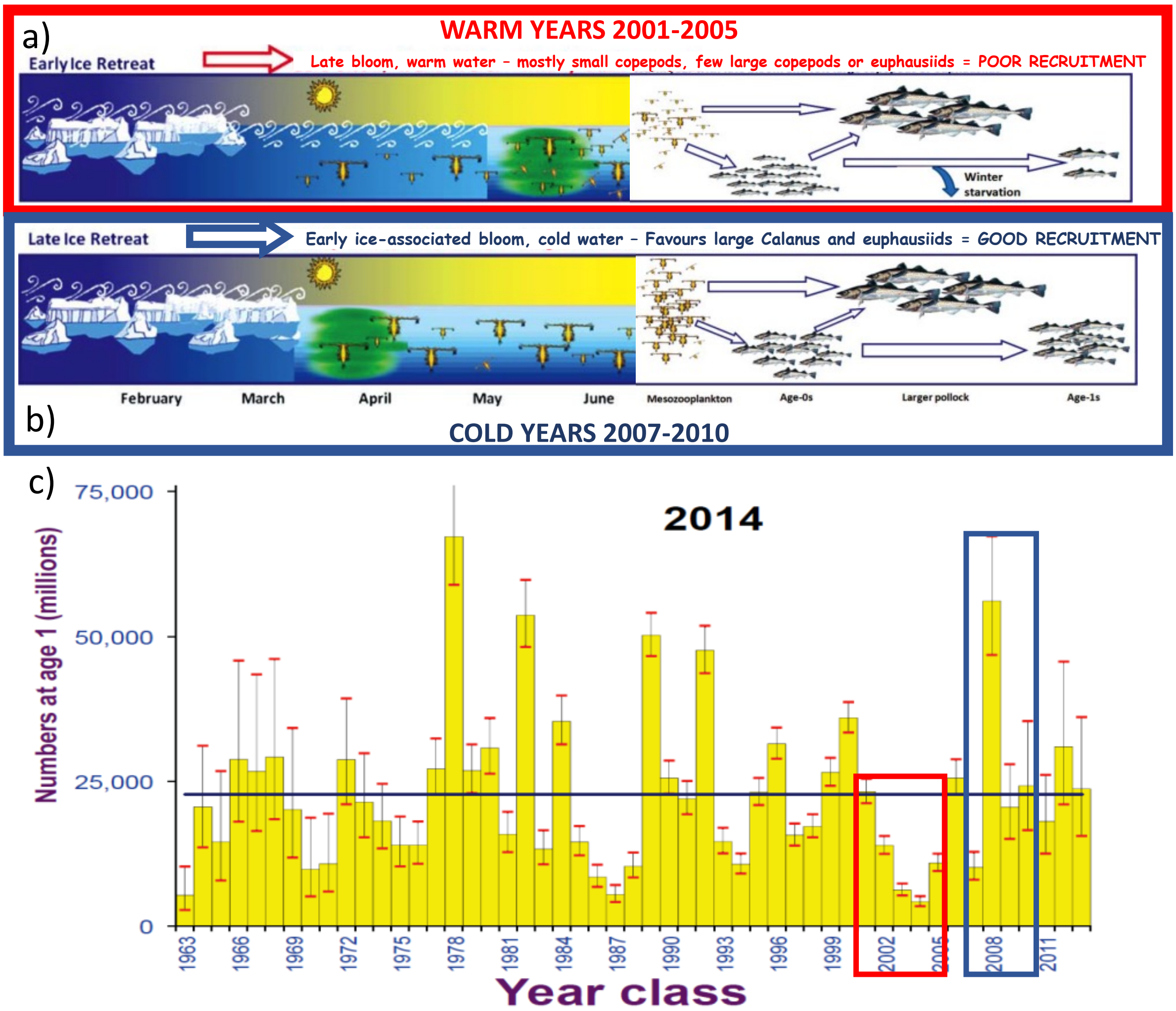

Figure 2). 5) The Critical Size Hypothesis indicates that recruitment is favored by conditions which provide for early growth, preparing the age-0 fish for overwintering; and 6) the Gas Tank Hypothesis builds on the latter invoking elements of Cushing's match-mismatch hypothesis to invoke temporal and spatial co-occurrences of zooplankton and pre-recruit pollock to provision for the winter and survival to age-1. The authors go on to recommend: seasonal monitoring programs; studies of predation, age-0 fish diet and condition; laboratory studies on growth and vital rates; spatially explicit ecosystem models; identification of critical areas (for spawning, nursery and feeding); competition with other species; and high resolution ageing. Another review paper, Sheffield Guy et al. (2014), highlights the major discoveries in relation to fisheries recruitment from 20 years of monitoring in the Bering Sea. Monitoring included 20 research cruises, three long-term mooring sites, over 40 drifters, and airborne measures of ocean color and temperature.

Much of the literature, and many of the presentations given at the review meeting, converges on the modified Oscillating Control Hypothesis to explain recruitment variation in walleye Pollack (Coyle et al. 2011, Hunt et al. 2011). This encompasses the work carried out by the RPA and its forerunners, on sea ice extent (Stabeno et al. 2012), the role of ice algae (Durbin and Casas 2013, Sigler et al. 2014), oceanographic & atmospheric conditions (Mordy et al. 2012), zooplankton (Eisner et al. 2014), euphausiids (Ressler et al. 2014), pollock egg and age-0 fish distribution and abundance (Siddon et al. 2013), and larval energetics (Heintz et al. 2013). It suggests that recruitment is favored by cooler periods, leading to a late ice retreat, more ice algae, an early phytoplankton bloom, and more of the large lipid-rich Calanus copepods and euphausiids. These prey are then available to the late age-0 fish, enabling them to store more fat reserves and so overwinter successfully to recruit as 1 year olds (see zooplankton abundance and energy density of zooplankton prey (Siddon et al. 2013); as well as oceanographic properties such as bottom water temperatures (Coyle et al. 2011). The systematic design is, therefore, entirely appropriate to estimate relative abundances, distributions, biomasses and to determine biological & physical properties as precisely as possible.

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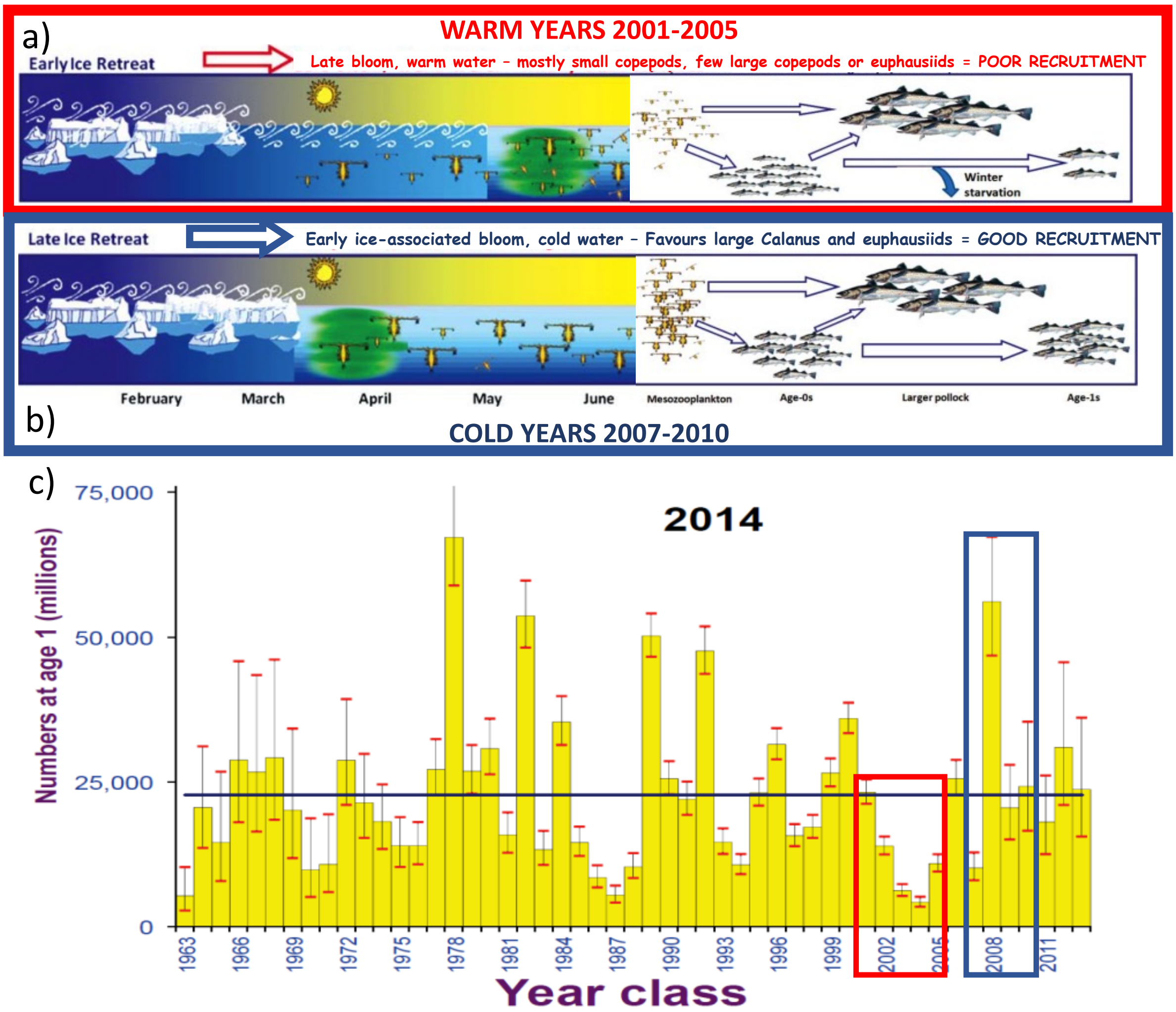

Figure 2). These prey also provide suitable prey for the adult fish, reducing cannibalism.

4.2 TOR 2. Evaluation of ecosystem surveys

Evaluate the historic, spring and late summer ecosystem and fishery survey designs, methods, and analytical approaches including data preparations and quantitative analyses to estimate the nutritional and behavioral ecology of target species (e.g. size, diet, energetic content, relative abundances, distributions, and biomasses, and associated uncertainties.)

4.2.1 Spring ecosystem surveys

Since 2001 there have been three broad types of survey design in the spring ecosystem surveys (Figure 3) differing only by the area covered. In each case the survey was designed to take oceanographic and concomitant biological samples in a systematic grid at 15 n.mi. spacing. Systematic surveys provide the most precise estimates of the mean quantity in the presence of autocorrelation (Rivoirard et al. 2000) and also provide for the best map. Autocorrelation was clearly evident in densities of pollock eggs and age-0 fish at various stages (Bacheler et al. 2010, Smart et al. 2012); in age-0 pollock, age-0 pacific cod, capelin (Smart et al. 2012, Parker-Stetter et al. 2013) and northern rock sole larval densities (*Cooper et al.* 2004); zooplankton abundance and energy density of zooplankton prey (Siddon et al. 2013); as well as oceanographic properties such as bottom water temperatures (Coyle et al. 2011). The systematic design is, therefore, entirely appropriate to estimate relative abundances, distributions, biomasses and to determine biological & physical properties as precisely as possible.

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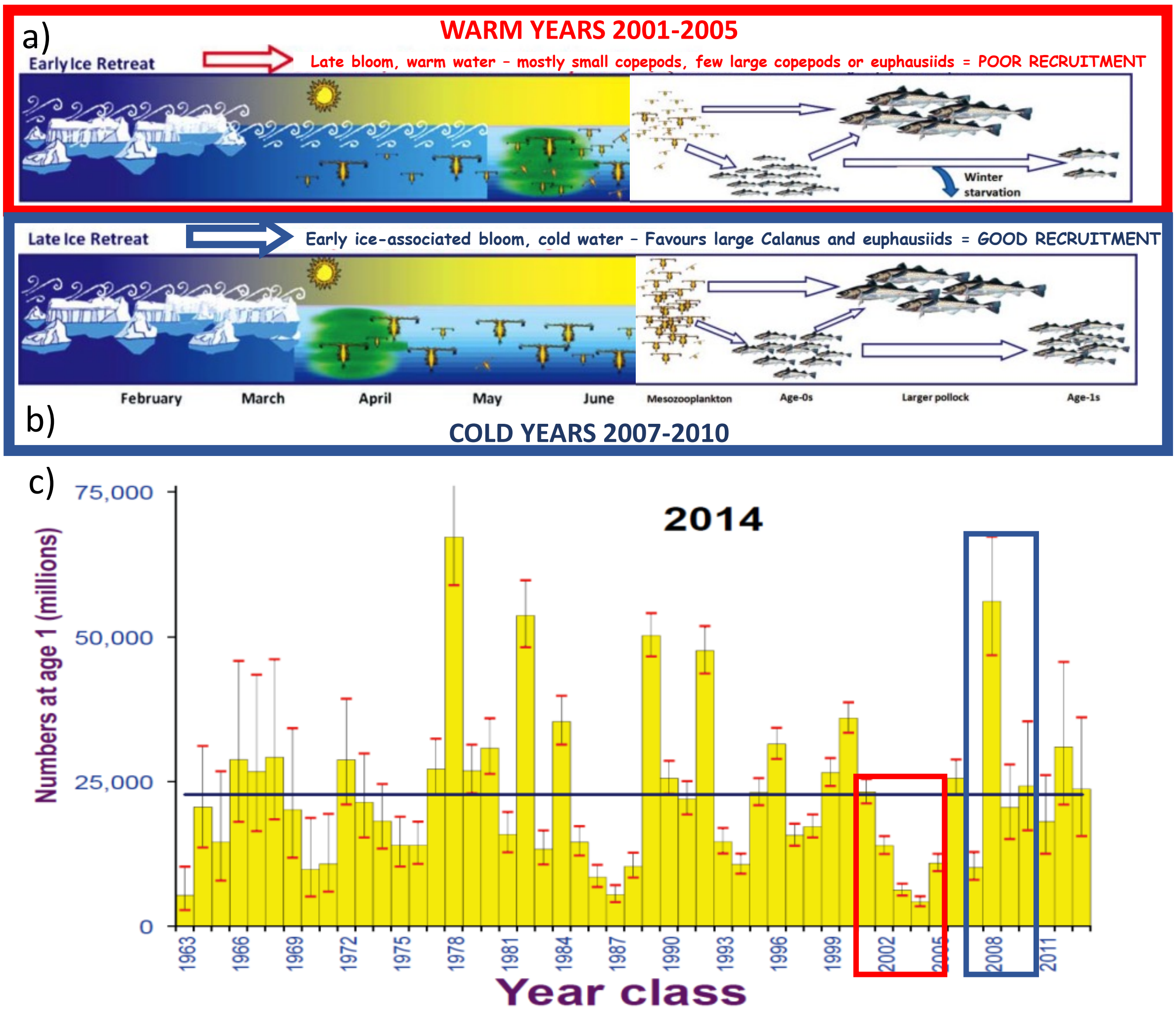

Figure 2. a) and b) Cartoon explaining the modified Oscillating Control Hypothesis to explain recruitment variation in walleye pollock from the eastern Bering Sea. Adapted from Hunt et al. (2011). c) Recruitment of age-1 pollock time series from the 2014 assessment, reproduced from Ianelli et al. (2014) indicating the warm (red box) and cold (blue box) periods.

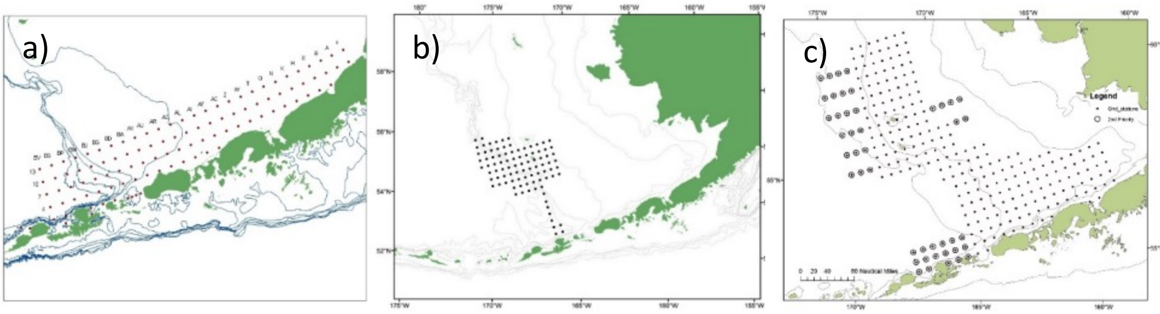

Figure 3. Maps of the eastern Bering Sea showing survey designs of the spring ecosystem surveys. a) the annual stations covered from 2001-2011; b) an example of an ad hoc process orientated design covering the Pribilof Islands; c) the design since 2012, undertaken biennially.

The methods and analytical approaches applied in the spring ecosystem surveys to estimate the nutritional and behavioral ecology have been widespread, and include: studies of spatial & temporal distributions (Bacheler et al. 2010), and penology (Smart et al. 2012), of age-0 pollock; age-0 fish species assemblages (Duffy-Anderson et al. 2006, Siddon et al. 2011); and inputs to various oceanographic and lower trophic level models (Gibson and Spitz 2011, Hermann et al. 2013). For most of these purposes the survey design is adequate, as a large number of samples from a wide area are guaranteed. The modelling efforts would benefit from wider areal coverage. Wider areal coverage might also be prudent ahead of future climate change given the likely changes in species distributions (Stabeno et al. 2012).

4.2.2 Late summer ecosystem surveys

Since 2000, a number of surveys have been carried out in the EBS in the later summer to sample age-0 fish in the surface waters, as well as taking oceanographic and planktonic whole water column samples (Figure 4). The survey was originally known as the Bering-Aleutian Salmon International Survey (BASIS) because it was developed to clarify the mechanisms of biological response by salmon to climate change (Farley et al. 2005). The remit for the survey was widened once it became apparent that it actually caught more age-0 walleye pollock: it then underwent a cunning name change to become the Bering Arctic Subarctic Integrated Survey. The survey design is systematic with stations at 30 n.mi. spacing. Autocorrelation was clearly evident in densities of various salmon species (Farley et al. 2005, Murphy et al. 2013) and capelin, age-0 pacific cod and age-0 pollock (Parker-Stetter et al. 2013). For reasons highlighted above, the survey design is entirely appropriate for estimation of density and mapping of a variety of variables. The long range autocorrelation that looks evident also lends justification to the sample spacing of 30 n.mi.

The BASIS fish sampling strategy, deploying a midwater trawl at the surface is, however, not particularly appropriate for sampling walleye pollock. Using echo sounders to sample the whole water column, Parker-Stetter et al. (2013) found low numbers of age-0 pollock in the surface zone and high densities in the midwater zone of the outer shelf region in 2009-2010. Although "juvenile Coho salmon maintain their highest densities in the upper 15 m of the water column" (Farley et al. 2005), "juvenile chinook salmon are distributed deeper", so the use of a surface trawl may not even be ideal for all salmon species. As a result changes are planned to sample the whole water column (see TOR 3).

The use of a surface deployed trawl should not have too great an effect on the studies of nutrition and condition that have come from BASIS on walleye pollock (Heintz et al. 2013) or pacific cod (Farley et al. 2015). Studies which have used relative abundances and distributions may have to be re-evaluated in the light of the variable vertical distribution of certain species, notably pollock. For example, the low densities or absence of age-0 pollock from northern areas in 2010 reported by Siddon et al. (2013) might no longer be considered accurate. In that particular year, Parker-Stetter et al. (2013) used acoustic data to describe a more widespread and more northerly distribution of age-0 pollock. Similar but less significant differences are evident in reports of the distribution of age-0 pacific cod (Hurst et al. 2012). These discrepancies highlight the limitations of using surface based samples for young fish which may occur throughout the water column and may change their vertical and horizontal distribution from year to year. They also bring to mind debates about persistence in time series data. The survey was designed for young salmon, most of which spend much of their time close to the surface. The desire to maintain time series no doubt led to the persistence of the technique even after the change of target species.

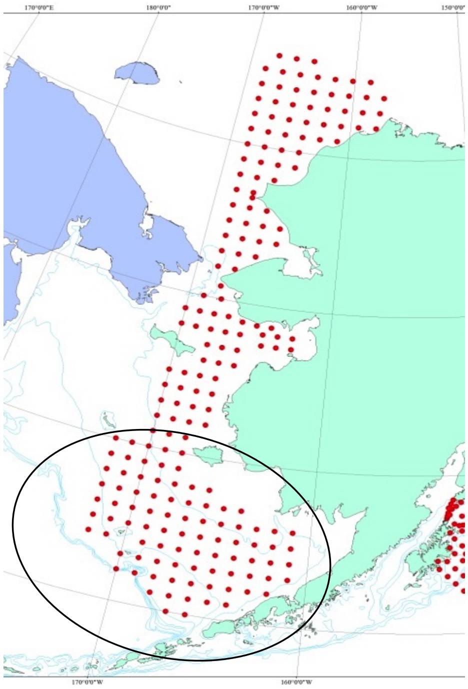

Figure 4. Map of the Eastern Bering Sea (EBS) showing the late summer ecosystem survey designs. The area circled in the southern EBS was where most of the BASIS surveys stations were located.

4.3 TOR 3. Evaluation of changes to the late summer survey

Evaluate the planned change in trawl survey design for the late summer survey design (surface trawl with midwater acoustics to oblique trawl with acoustics), methods, and analytical approaches including data preparations and quantitative analyses to estimate the nutritional and behavioral ecology of target species (e.g. size, diet, energetic content, relative abundances, distributions, and biomasses, and associated uncertainties.)

The planned change to the late summer survey is to change the deployment of the principle young fish sampling tool, a midwater trawl, from deployment at the surface to an oblique configuration sampling the whole water column. Given the experiences highlighted above (see 4.2.2), essentially describing the situation of limited [vertical] availability to a surface based sampling device, this suggestion, although an improvement, may suffer from another problem in the horizontal dimension. The autocorrelated [patchy] nature of [young] fish distribution means that there will be sequential locations (sampling stations) where there will be little if any fish, followed by patches of presence, with varying density. Time spent sampling empty water could be best employed surveying elsewhere, either beyond the confines of the current survey or within areas of high density [and by extension, high variance] to improve precision. The acoustic equipment, specifically the scientific echosounder, can detect and determine densities of age-0 fish (Parker-Stetter et al. 2013, De Robertis et al. 2014): any biological sampling should, therefore, be carried out on the acoustically detected densities. This makes for an ad hoc biological sampling process as described in Simmonds and MacLennan (2005) which ensures that the appropriate aggregations of fish are sampled, lending itself to studies of fish size and other work requiring biological samples (diet, energetic content).

In terms of relative abundance, distribution and biomass, the tool to use is the scientific echosounder. The feasibility of applying an acoustic survey to estimate the abundance of walleye Pollack is detailed in De Robertis et al. (2014). They not only conclude that the method is feasible, but indicate that the estimates of age-0 pollock are robust to the usual acoustic survey assumptions (target strengths, verification of targets through net sampling and net selectivity). The RPA is fortunate to have the expertise of the Midwater Assessment and Conservation Engineering (MACE) within the RACE Division. The MACE program, which deals with acoustic technology as well as other advanced survey technologies, has extremely well qualified and experienced personnel; it also has a suite of advanced survey tools, of high scientific "industry" standard, as well as new cutting edge developments, some of which are their own, such as cam-trawl (Williams et al. 2010). Their inputs, through the acoustic survey of adult pollock, are vital to the stock assessment of walleye pollock (Ianelli et al. 2014). The RPA would do well to engage with MACE and benefit from their expertise in sampling to improve the late summer survey.

This reviewer is of the strong opinion that the planned change does not go far enough: BASIS should move to a full blown acoustic survey with appropriate biological sampling as recommended in De Robertis et al. (2014). The current stations can be maintained for oceanographic and planktonic sampling: the survey design could effectively remain the same [notwithstanding de De Robertis et al.'s (2014) recommendations]. The time saved with ad hoc sampling for acoustic surveying should be evaluated: this may provide time for areal extensions to the survey, or it may not because some time will be taken up with the requirement to stop surveying (acoustically) at night (although oceanographic and plankton samples should still be taken at night to save time). MACE should be encouraged to apply some of their innovative sampling tools in the survey where resources allow: this includes the aforementioned cam-trawl but also the new broadband sonars which are capable of providing extremely high resolution data. Discussions with the head of MACE indicated a desire to develop an analysis system in an open source software platform which would be capable of facilitating the analysis of species mixtures during an acoustic survey such as BASIS. The reviewer recommends that this system be developed and applied because, in the medium term, it will save significant personnel resources from both MACE and RPA in dealing with the analysis of the acoustic survey.

4.4 TOR 4. Evaluation of an oblique trawl survey

Evaluate the trade-offs, in terms of costs, benefits, and consequences, of transitioning the late summer survey from surface trawl with midwater acoustics to an oblique trawl survey, particularly regarding its potential to provide comparisons between historical and future nutritional and behavioral ecology of target species.

The trade-offs in terms of costs, benefits and consequences of transitioning the late summer survey to i) an oblique trawl survey; and ii) an acoustic survey per-se are given below in Table 1. The comparisons to historical data are less relevant if the historical data are considered to be biased (see section 4.2.2). Some investigation would be required to determine what are the main factors influencing the vertical distribution of walleye pollock in order to qualify previous results from the surface towed sampling device. Transitioning to a whole water column sampling system is a priority. The acoustic survey is by far the better option (Table 1), although some initial investment in training personnel and developing analytical methods will be required.

Future studies of nutritional and behavioral ecology will also benefit because all sampling carried out during an acoustic survey is directed to targets of interest, so there are likely to be more samples. More importantly, these samples will be scaled appropriately and can be located at high resolution in the three dimensions that they are actually encountered in. Examples of such work include multi-trophic studies of age-0 pollock at frontal systems (Schabetsberger et al. 2000, Ciannelli et al. 2002) and nursery areas (Swartzman et al. 2002). Some concerns were raised about potential differences in estimates of the average weight of pollock and average energy content between surface and midwater samples.

Table 1. Cost benefit table evaluating young fish sampling options for the EBS late summer ecosystem survey.

		Oblique trawl	**Acoustic survey**	**Balance in favor of:**
Costs	Biological sampling device	None, if new trawl purchased?	None, if use modified Marinovich trawl (Arctic EIS).	Equal
	Additional equipment	None.	None, if Oscar Dyson used (echo sounders on board).	Equal
	Time (Days at sea)	Likely to incur more time than previous surface towed sampler.	Likely to incur less time sampling, but more time due to stopping at night and requirement for calibration.	Acoustic, but needs examination
	Personnel: Shipborne	Medium. After initial training new sampling device should be similar to previous.	Initially high. New personnel would need to be trained in-situ by MACE.	Oblique (short term) Equal (long term)
	Personnel: Analysis	Low. As per previous sampler.	Initially high. New system would need to be developed by MACE. Once developed costs will be low.	Oblique (short term) Acoustic (long term)

Benefits	Samples whole water column.	Samples whole water column, but distinguishes targets at high vertical (20 cm) and horizontal (5 m) resolution enabling 3D localization to inform vertical as well as horizontal distribution patterns, and potential oncogenic structuring in the water column. Continuous sampling along entire transect, distinguishing oceanographic features such as pycnocline, internal waves, planktonic scattering at high resolution. Samples other targets such as euphausiids, adult fish and plankton (and by inference, internal waves and other oceanographic turbulent features).	Acoustic
Consequences	Frequent occasions of sampling empty water. Horizontal and vertical annual heterogeneity will potentially lead to a biased index, certainly less precise.	Best available method to estimate indices of abundance from targets distributed throughout the water column. Will require collaboration with MACE and concomitant investment in resource, particularly in the short term.	Acoustic

However, these differences were not systematic and may reflect the low precision and differential spatial locations of the samples. Equally they may reflect genuine ontogenic differences which account for vertical position in the water column. Acoustic data would enable the exact position in the water column to be determined, which is another reason to move to this technique.

4.5 TOR 5. Evaluation of surveys for various applications

Evaluate the potential of the spring and late summer ecosystem and fishery survey designs and analyses, or an alternative, to (i) be applied to coupled biophysical-individual based modeling and trophic modeling approaches currently in use, ii) resolving mechanistic linkages among ecosystem components, and (iii) be applied to management and conservation of walleye pollock, Pacific cod, and arrowtooth flounder within an Ecosystem Based Fishery Management approach.

4.5.1 Potential of surveys to be applied to ecosystem models.

One of the many excellent partners in the RPA is the Resource Ecology and Fisheries Management Division's (REFM) Resource Ecology and Ecosystem Modeling (REEM) task. This group collects and analyses data on trophic interactions and incorporates these into multi-species and ecosystem models. There are three models which have multi-trophic interactions: CEATTLE, EcoPath with Ecosim (EwE) and FEAST. The former are still in development and this reviewer could find no references to specific EBS versions of them in the literature. The reviewer understands that EwE is, however, at an advanced stage of development: this is to be encouraged as it is the most complete representation of the entire food web (including top predators such as marine mammals and seabirds for example).

The Forage-Euphausiid Abundance in Space and Time model (FEAST) is stacked onto models of lower trophic levels (NPZD & downscaled ROMS). FEAST has impressive spatial and temporal resolution, but takes a long time to run (due to the high temporal resolution ROMS model). Data from the surveys that are used to parameterize (validate) the model include fish size at age, fish egg hatch timing and initial sizes, age-0 fish diets, age-0 fish distribution, bioenergetics (including energy densities of prey and vital rates related to temperature), movement drivers (towards prey fields and away from predator fields) and zooplankton seasonality (out with winter). These are key components and given the comprehensive nature of the food web included in the model, make for much better parameterization. The reviewer is a work package leader for a large European consortium developing ecosystem models in seven areas around Europe. In no case are data of this quality and frequency available to these models and most of the lower trophic level parameters in particular are approximations from literature values as oppose to being estimated with the benefit of real data. Moves are afoot to collaborate with the RPA modelling team through "twinning" (European Union funded partnerships).

4.5.2 Potential of surveys to be applied to resolving mechanistic linkages among ecosystem components.

Understanding the relationships between climate, ocean physics, nutrients, primary productivity, secondary productivity and survival of age-0 fish is key to accepting or modifying hypotheses like the modified OCH (zooplankton abundance and energy density of zooplankton prey (Siddon et al. 2013); as well as oceanographic properties such as bottom water temperatures (Coyle et al. 2011). The systematic design is, therefore, entirely appropriate to estimate relative abundances, distributions, biomasses and to determine biological & physical properties as precisely as possible.

Initial surveys (prior to 2012) were process orientated and so the areas covered targeted specific species and/or stages (e.g. Figure 3b). The regular grid surveyed initially (Figure 3a) was expanded in 2012 (Figure 3c) to cover a larger area inclusive of more pollock and Pacific cod spawning areas in the Pribilof and Unimak islands. The latter design includes additional stations beyond the limits of the regular survey area which are given lower priority. Although the full northern extent of the spawning range of walleye pollock may not be always covered - e.g. Zhemchug Canyon (see Figure 1) has been reported as being important for spawning (Stepanenko and Gritsay 2014) - spawning in the north-western areas occurs later in the summer (Hinckley 1987), so the area coverage is probably appropriate for the time of year. However, given the variable nature of recruitment (Bacheler et al. 2010), some form of adaptive coverage might be appropriate to capture more extensive spawning events, whilst maintaining the core area delineated in Figure 3c (see recommendations in Section 6).

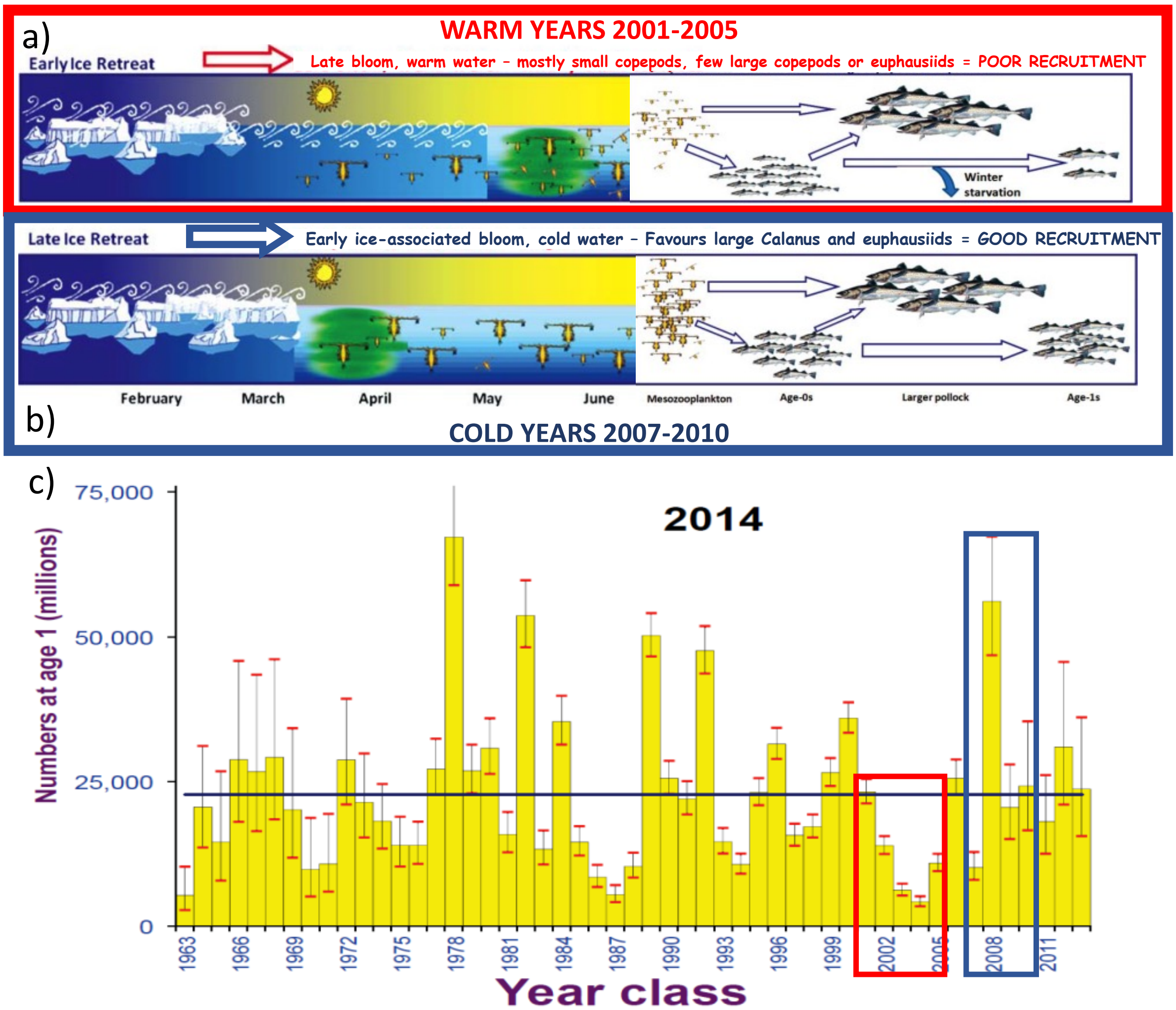

Figure 2) and/or rejecting the five alternative hypotheses described in Section 4.1. In the modified OCH, the leap from climate (yearly temperatures) to age-1 recruitment of walleye pollock, the ultimate bottom-up control mechanism, is large and complex. There are probably spatial elements (Siddon et al. 2013), extreme episodic events and atmospheric influences to consider, which may mean that tactical predictions will be difficult to make. However, the information gathered by RPA to understand these mechanisms is at least likely to reassure stakeholders that there is cause and effect and that there are reasons to adhere to scientific advice. Understanding the mechanistic links among ecosystem components is key to providing additional evidence in support of a tactical assessment and catch forecast. An example of this is provided in the North Pacific Fisheries Management Council's Scientific and Statistical Committee (NPFMC SSC) minutes of 2006, using data gathered from the RPA surveys, and include statements such as: "a large decline in zooplankton, which is important in providing forage for juvenile pollock" and "increasing predation by arrowtooth flounder on juvenile pollock, which could contribute to further declines in adult pollock biomass"; leading to the conclusion that "Consequently, the SSC agrees with the Plan Team that a reduction in Allowable Biological Catch from the maximum permissible is justified".

4.5.3 Potential of surveys to be applied to management and conservation of walleye pollock, Pacific cod, and arrowtooth flounder within an EBFM.

Examination of the assessment of walleye pollock (Ianelli et al. 2014) indicates that catch forecasts are based on projections of the population which begins with the numbers estimated in the year of assessment, are then projected forward to the next year using the natural mortality and selectivity determined in the assessment and the best available estimate of catch for the year of assessment. In each subsequent year the fishing mortality rate is set based on the spawning biomass and the respective harvest scenario. Recruitments are simulated from statistical distributions whose parameters are derived maximum likelihood estimates from recruitments in the assessment. Exactly the same procedure is used in the forecast for catches of Pacific cod (Thompson 2014) and arrowtooth flounder (Spies et al. 2014).

In the case of pollock, cod and arrowtooth flounder, the projected catches are based on age 3+ fish, so even if the BASIS surveys were to provide an index that could be indicative of age-1 fish, this would not have any impact on the forecast. Whether such an index would be useful to the assessment per se is debatable. As discussed in Section 4.5.3 above, these surveys serve well to explain annual recruitment variability, providing additional evidence to maintain confidence in the scientific advice.

The BASIS survey does contribute information which appears in the walleye pollock assessment reports section on "Environmental factors affecting recruitment". For example, Ianelli et al. (2014) state "when sea temperatures on the eastern Bering Sea shelf are warm and the water column is highly stratified during summer, age-0 pollock appear to allocate more energy to growth than to lipid storage, leading to low energy density prior to winter. This then may result in increased over-winter mortality." No reference to the BASIS surveys could be found in in either the Pacific cod (Thompson 2014) nor the arrowtooth flounder assessments (Spies et al. 2014): there is potential, therefore, for the output from the RPA to be included in these.

The North Pacific Fishery Management Council (NPFMC) produce an annual report on Ecosystem Considerations, e.g. Zador (2013), which provides a succinct report card on the Eastern Bering Sea and Aleutian Islands ecosystems. This is based on examination of over 75 indices dealing with climate, oceanography, plankton, fish, marine mammals, seabirds and the fisheries. The BASIS survey provides information for the indicators on forage fish, jellyfish and energy density of age-0 pollock. Presumably, the energy density of Pacific cod could be added (Farley et al. 2015). The report also includes a section on "hot topics" which in any one year could merit from a contribution from the RPA (if not already?).

4.6 TOR 6. Evaluation of surveys to provide Chinook salmon cap

Evaluate the potential of the late summer ecosystem and fishery survey design and analysis, or an alternative, to incorporate these data in a western Alaska Chinook salmon 'abundance based cap' for prohibited species catch within the Bering Sea walleye pollock fishery in comparison to the proposed 'abundance based cap' using estimates of adult western Alaska Chinook salmon returns as proposed within the North Pacific Fishery Management Council.

Alaska chinook salmon have long been a bycatch problem walleye pollock fishery (Ianelli and Stram 2014). Bycatch peaked in 2007 at over 120,000 fish, and in 2011 an absolute limit (cap) was introduced, combined with industry designed incentive programs to reduce bycatch (annual closures, excluder devices and vessels moving away from high bycatch rates). The caps are set at 60,000 but the fishery is managed at a lower cap level of 47,000. Current bycatch levels are between 11,000 and 25,000 and have a low impact on the adult returns: bycatch mortality was around 2% in 2011 and 2012 (Ianelli and Stram 2014). The NPFMC is considering new action in 2015, amongst which is an abundance based cap, with lower caps (reduced by 25 to 60%) in years of low Chinook abundance (<=250,000). The abundance based cap would be determined each year and tied to an index of Chinook runs in 3 indicator systems the previous year. This makes it a lagging indicator, and relies on the number of fish in the ocean in any one year being related to the number of fish returning to rivers the previous year.

The late summer ecosystem survey catches juvenile Chinook and chum salmon effectively, which is not surprising as it was designed for those species. Furthermore, Murphy et al. (2013) found that juvenile abundance of the Canadian-origin stock group was positively correlated with adult returns. The BASIS juvenile salmon indices could, therefore, be used as leading indicators of future returns and used to set or modify the bycatch cap. Discussions at the review involving David Witherell, of the North Pacific Fisheries Management Council, seemed to indicate the fishing industry may be willing to fund this survey so that a more appropriate cap could be used. This survey would have to be based on an industry charter, which would be cheaper than using the Oscar Dyson (to industry at least), because it would need to get into shallower water in order to catch more of the juvenile salmon which occur closer to the coast (Fig. 5). The reviewers all agreed that this new option should be considered, as it was likely to provide better information to inform a cap (using a leading indicator rather than a lagging one) and would also free up the Oscar Dyson to concentrate on other things.

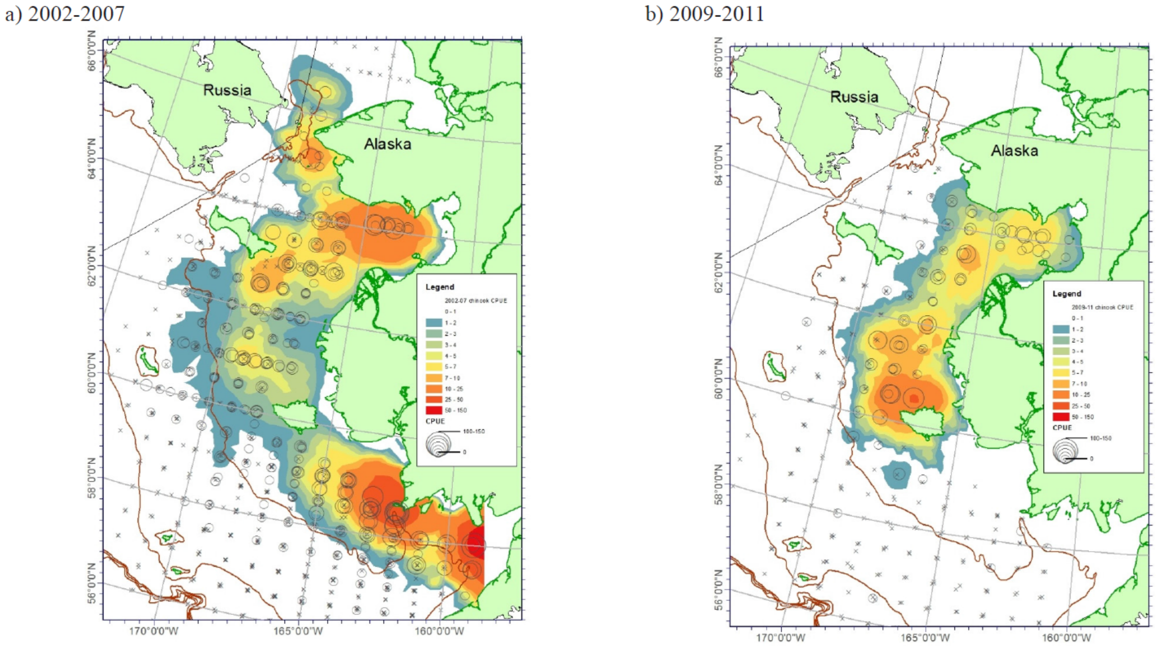

Figure 5. Map of the EBS showing the distribution of Chinook salmon catch-per-unit-effort from the BASIS surface trawl surveys, with the mean shaded according to the legend: a) 2002-2007; b) 2009-2011. Reproduced from Murphy et al. (2013).

4.7 TOR 7. Evaluation of survey timing

Evaluate the tradeoffs, in terms of costs, benefits, and consequences, of: 1) separate Chinook salmon and walleye pollock, Pacific cod, arrowtooth flounder surveys every year or every other year, with or without ecosystem sampling; and 2) joint Chinook salmon and walleye pollock, Pacific cod, arrowtooth flounder surveys every year or every other year, with or without ecosystem sampling, particularly regarding their potentials to: i) evaluate the nutritional and behavioral ecology of Chinook salmon, walleye pollock, Pacific cod, arrowtooth flounder, and ancillary forage species; ii) put that information into the context of their biotic and abiotic environments; and iii) characterize their roles in the eastern Bering Sea Ecosystem. Provide specific recommendations for short- and long-term improvements to anticipated compromises associated with spring and late summer ecosystem surveys.

The trade-offs in terms of costs, benefits and consequences of conducting separate or joint surveys, and their frequency are given below in Table 1. Given the conclusions in Section 4.4 these are being considered with the transition to an acoustic survey. There is also an assumption, given the discussions had with industry representatives (see Section 4.6), that the walleye pollock fishing industry would be willing to fund an industry charter to carry out a survey that would deliver a leading indicator which could be used to set the salmon bycatch cap. An industry vessel would be more suited to surveying salmon in any case, as the current

BASIS platform (Oscar Dyson) cannot operate in coastal areas where salmon are likely to occur.

Table 2. Cost benefit table evaluating additional options for the EBS late summer ecosystem survey. Separate surveys would take place on an industry charter (with limited ecosystem sampling) and the Oscar Dyson; joint surveys would be either on the Dyson or an industry charter with limited ecosystem sampling.

		Separate surveys	**Joint surveys**	**Annual**	**Biennial**
Costs	Biological sampling device	Low, can allocate existing surface trawl to industry charter, use other trawls for Oscar Dyson.	Low, as per status quo, but with ship time implications (see below).	Medium, in long term more wear and tear on gear	Low, as per status quo.
	Ship time (Days at sea)	Low, as per status quo: Zero cost if industry could fund salmon survey as suggested.	Low, if use Oscar Dyson, but may need longer to deploy surface trawls as well as midwater trawl for acoustic survey. Zero cost if industry could fund joint survey.	Zero cost if industry could fund salmon survey, or joint survey.	Low, if use Oscar Dyson
	Personnel: Shipborne	Medium, would need to send 2 more scientists on board industry vessel to sample.	Low, approximately as per status quo.	Medium, would need to send scientist on board industry vessel.	Low, as per status quo
	Personnel: Analysis	Medium, additional survey to design, prepare for and analyze.	Low, approximately as per status quo.	Medium.	Low, as per status quo
	Other		If on industry charter, would need to obtain acoustic survey equipment (as per MACE AVO prog).		
Table 2 continued		**Separate surveys**	**Joint surveys**	**Annual**	**Biennial**

Benefits	Industry potentially main beneficiary, if leading indicator can be used to set Chinook salmon bycatch cap. Other data on salmon at sea obtained for linking with ecosystem information determined from other sources.	Joint survey could also provide leading indicator for bycatch cap if carried out by industry charter. Industry charter could also do ecosystem survey provided sufficient berths for all scientists (3?).	Leading indicator to inform salmon bycatch cap. Annual time series of separate ecosystem surveys will catch sporadic high or low recruitment year.	Maintains time series, but at lower temporal resolution. Frees up resources (Dyson et al) to do other things every other year.
Consequences	No ecosystem sampling on industry vessel unless even more personnel involved.	Oscar Dyson cannot sample salmon closer to coast. Convincing industry to fund or part fund (e.g. ship time) a joint survey should be achievable and frees up Oscar Dyson for other things. May need to take longer to do joint surface trawl and opportunistic midwater trawl, but as industry funds, should not be an issue other than for staff time.	Leading indicator for salmon bycatch cap would need to be annual. May be locked in for some time: perhaps with gradual move to train up industry to do it independently.	Not feasible for leading indicator to inform bycatch cap. Ecosystem surveys may miss sporadic high or low year class.

On balance, considering the costs, benefits and consequences of the various options, this reviewer would recommend the following be considered in a suggested order of preference:

1. A joint acoustic survey, covering the whole BASIS area, carried out and part funded by an industry charter (including the inshore areas previously inaccessible to the Oscar Dyson). This survey would sample both the surface waters with the current midwater net, and the whole water column with a modified Marinovich trawl as recommended in De Robertis et al. (2014). Oceanographic and plankton sampling tools should be taken to sample the ecosystem. The walleye pollock fishing industry should be approached to fund the charter, supplying a vessel with two net drums to accommodate the two trawls. As this would save on NOAA ship time, it could be carried out annually, providing an annual leading indicator of salmon at sea abundance, and appropriate age-0 fish indices for all other species (pollock, arrowtooth flounder and pacific cod), as well as ecosystem sampling. It will also build and enhance the expertise in MACE's Acoustic Vessels of Opportunity (AVO) program.
2. Separate surveys for the salmon at sea and age-0 fish. Industry should be approached to fund a charter for the salmon at sea surveys, which should be conducted annually and include the inshore areas. In this case the industry charter would simply conduct surface

trawling. The age-0 fish acoustic survey should take place biennially with full ecosystem sampling on the Oscar Dyson. The Dyson survey would not conduct surface trawling.
3. Biennial age-0 fish acoustic survey with full ecosystem sampling on the Oscar Dyson. If industry cannot be convinced to part fund the salmon at sea survey, then this reviewer would suggest shelving it. It would be too expensive to justify running a survey to determine a salmon at sea index which would be used primarily to set a bycatch cap for the walleye pollock industry. Some salmon would be caught on the Dyson under this option and this should be evaluated prior to embarking on a NOAA funded salmon at sea survey.

4.8 TOR 8 Evaluation of gaps and inconsistencies

Evaluate gaps and inconsistencies in process research, particularly regarding the potential of research practices to provide mechanistic information to Integrated Ecosystem Assessments and Ecosystem Based Fishery Management practices.

4.8.1 Oceanography and the link to primary & secondary production

The modified Oscillating Control Hypothesis suggest that the early ice associated blooms provide good conditions for the lipid rich copepods *Calanus marshallae* and the euphausiid *Thysanoessa raschii* (Hunt et al. 2011), which in turn then provide high quality food for the age-0 pollock as well as the adults, enabling the former to overwinter more successfully. Future process orientated studies should investigate these two plankton species more closely to determine what dictates their success. The role of sea ice and ice algae in particular is key (Leu et al. 2011). Euphausiids have a strong association with sea ice (Loeb et al. 1997, Brierley et al. 2002) as do Calanoid copepods (Durbin and Casas 2013). So the role of sea-ice algae and these two species should be a focus for future studies, particularly in relation to future climate change. Modern sampling tools, such as underwater moored echosounders (Miksis-Olds et al. 2013) and autonomous underwater vehicles (Brierley et al. 2002) allow for detailed under-ice observations which would help understand these links better. The uncertainties in biomass estimates of euphausiids could be reduced by developing an annual euphausiid abundance indicator based on the new acoustic survey (De Robertis et al. 2014). Monitoring plankton populations throughout the year in a cost effective manner should be investigated to determine the extent and timing of the spring blooms. Further collaboration with the Pacific Continuous Plankton Recorder program (Batten and Bychkov 2014) should be considered as this has a 15 year time series of data which includes the southern Bering Sea which may be useful and could be expanded upon.

Wind stress is an important factor in the timing of blooms affecting both surface mixing and eastern Bering Sea shelf circulation (Danielson et al. 2012). Why do the climate models predict future wind stress to be greater when empirical data suggest mean wind speeds globally are reducing? [see You et al. (2013) their Table 2]. Has a long term time series of wind speed in the area been put together (as oppose to indices of extreme events such as storms)? The assumption that wind stress will increase under climate change should be investigated.

4.8.2 Young fish surveys & biology

Understanding pollock and other species vertical migration is an important ecological element that will contribute to a better understanding of their survival. This is an extension to the general understanding of the three dimensional distribution of key predators and prey in the EBS. The new BASIS acoustic survey will allow for this three dimensional understanding by providing data not only of the vertical distribution at very high resolution (20 cm) but also detailed along track horizontal distribution at high resolution (5 m). Linked to this 3-D distribution is a better understanding of the boundary conditions of age-0 pollock in term of limits to the distribution and how they change with environmental (bottom-up) and other (top-down) effects. The role of arrowtooth flounder, given its continued rise in the area (Spies et al. 2014), should be examined further, particularly the balance between its two key prey pollock and euphausiids: does this change in accordance with the modified OCH? The distribution of predators and prey in three dimensions would help to provide further evidence for any match-mismatch hypothesis (Siddon et al. 2013) which may add a spatial dimension to the modified OCH. The suggestions highlighted in this report, to increase coverage of the spring surveys and to move to an acoustic survey in the late summer should all help to improve the knowledge of distributions of both predators and prey that are important in recruitment processes.

Understanding overwintering in the first year of pollock would also be valuable, although this period presents extreme challenges due to the nature of the environment at this time of year. Making use of the advanced technologies described above (see Section 5.1) on moorings, AUVs or gliders might be explored in ad hoc distributional studies.

Enhanced collaboration with other institutes, particularly foreign interests in the fishery should also be investigated. The review material was dominated by publications from personnel within the RPA, for obvious reasons, but what contributions are being made from elsewhere? A cursory search for specific topics revealed some key contributions that were not mentioned (Durbin and Casas 2013, Batten and Bychkov 2014, Stepanenko and Gritsay 2014). Although time could not permit a completely exhaustive review of all literature, this reviewer has been left wondering how much international collaboration there has been? If international collaboration networks are well established and in place, then some evidence should be provided to demonstrate the added value of; if not, then they should be instigated.

4.8.3 Modelling

Why does the FEAST model predict a secondary peak in the production of small phytoplankton in week 43 (end of October, when daylight occurs for approximately 9 hours)? Why is this higher than the first peak of production? Some evidence for this needs to be found as well as an explanation. This could be link to enhanced monitoring of plankton described above (Section 5.1). The model is incredibly well linked to oceanography and produces some remarkable spatial outputs: these should be published as soon as possible. There are no doubt plenty of model refinements due, but in terms of recruitment, it would be useful to incorporate the production of eggs and to then track their mortality to close the loop on stock recruitment.

Key sensitivities of the model should be explored: in particular the functional responses of key predators such as arrowtooth flounder. An alternative ecosystem model, such as Ecopath with Ecosim, should also be developed or completed as a priority, given that "all models have strengths and weaknesses and multi-model ensemble approaches are preferred" [Bond pers. Comm. RPA review, 21 July 2015; Smith et al. (2011)].

4.8.4 Management and advice

The flounder and pacific cod assessments do not contain any reference to the RPA products. The focus to date has been on pollock, and the collaboration between the RPA and the pollock stock assessment team is clearly very good: lessons learnt there should be translated into these other assessments.

The philosophy of using RPA products to qualify management advice is good, but can be expanded to prepare for future scenarios, for example, related to climate change. In that regard, the hypotheses articulated at the review as considered by the RPA are relevant:

1. Ho: Climate change and variability have predictable effects on the bottom-up and top-down mechanisms which regulate fisheries recruitment in Alaska.

2. Ho: The effects of climate and ecosystem function on fish recruitment are most evident during two critical periods: 1) the early to late larval stage when mortality is a function of growth rate, and 2) the first winter when mortality is a function of size and energetic status obtained during the previous summer and fall.

The presentations given and the wealth of literature provided suggest that significant progress has been made to test the second of these. It is less clear what the effects of climate change will be. Climate change models have been applied to the region to predict oceanographic conditions, but there was less evidence for the long term effects on the ecosystem. This may be due to the emerging nature of the ecosystem models being used for long term forecasts. A key question will be how the enhanced sea surface temperature and less ice will affect the ecosystem and subsequently what impact it will have on recruitment. Will primary & secondary production increase as is predicted in polar ecosystems (Steinacher et al. 2010)? What will this mean for the quality of zooplankton prey that is key to pollock survival in its first winter? Is sea-ice persistence key to high pollock recruitment? These are just three of many questions that the RPA is uniquely qualified to address through inter-disciplinary research and long term monitoring. Some long term planning for what remains one of the biggest fisheries in the world might be prudent once the answers to these questions arise.

5 Conclusions and Recommendations

1. The Recruitment Processes Alliance is a remarkable consortium consisting largely of government funded research organizations which have come together to try to answer one of the biggest questions in fisheries ecology in one of the world's biggest fisheries: what drives recruitment variability in walleye pollock? This reviewer can think of no other comparable integrated marine program which has such a wealth of resources, expertise and experience and, as such, the RPA is world class. The nearest comparable ecosystem based research program is the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program (Constable 2011) which aims to monitor land-based predators to detect effects of the krill fishery on the ecosystem. The RPA with its well-integrated disciplines of oceanography, plankton ecology, young fish ecology and ecosystem modelling is to be highly commended.
2. The monitoring program should be continued where possible. In cases where there is an obvious benefit to the fishing industry, such as the development of a leading indicator to set appropriate salmon bycatch caps in the late summer [BASIS] survey, the industry should be approached to part-fund the survey.
3. The BASIS survey should be changed to an acoustic survey (Simmonds and MacLennan 2005). This will allow for three dimensional characterization of the distribution of targets at high resolution (at least 20 cm in the vertical and approximately 5 m in the horizontal along sampled transects). If a suitable industry platform can be found which can deploy nets at both the surface (for salmon) and in the water column (for age-0 fish and others), then a combined survey should be carried out to include the nearshore areas where salmon occur. This could then be conducted annually depending on the funding model. A range of possibilities is discussed in Section 4.7.
4. The new BASIS acoustic survey should provide an index of euphausiid abundance.
5. An opportunity should also be taken at this time of change to reconsider the design of the BASIS survey. The stations currently sampled could remain, considered as core, but some near shore stations would need to be added to sample salmon if a combined approach is adopted. De Robertis et al. (2014) also recommend a re-examination [expansion] of the area to where age-0 pollock are expected to occur at that time to remove edge effects

(survey boundaries with large numbers of fish). The move to an acoustic survey will require cessation of acoustic data collection at night, so the balance in timing of all of these measures needs to be evaluated for the new survey design.

6. The spring ecosystem survey design should be changed in the light of previous results to expand the area and reduce the intensity in the along-shelf direction. An analysis of [anisotropic] autocorrelation of variables of interest should be conducted to determine an appropriate sampling intensity which could be achieved without losing too much precision. This can be augmented by subsampling (at alternative sampling intensities) some of the historical surveys to estimate some of the variables to confirm that estimates are consistent. Much will depend on the statistical properties of the variables, particularly the influence of extreme values at the higher trophic levels, which may, or may not, be subsampled, so robust estimation methods should be considered where appropriate (see ICES (2004), (ICES 2005)).
7. The spring ecosystem surveys should also incorporate an adaptive survey design, with coverage of the Unimak pass and potential expansion of transects east, west and north of a core area. An example, of such an adaptive design is that employed for mackerel eggs in the North East Atlantic ICES (2014). The core area should encompass the present area covered by all grid stations (priority and 2nd priority, Fig. 2c), but sample intensity should be reduced to a 30 n.mi. transect spacing (or other, depending on outcome of studies recommended in 1 above), maintaining the 15 n.mi. sample spacing across the shelf (approximately east-west) to capture the higher variability in that direction (Siddon et al. 2011). This should cut the sampling time for the core area by approximately half, allowing for expansion into the aforementioned areas without much loss of information because of the long range autocorrelation that is evident in most of the variables that are measured. Given the three age-0 fish species clusters identified by Duffy-Anderson et al. (2006), more intense sampling strata might be considered in the Pribilofs, Middle domain, and Outer domain relative to the rest of the core.
8. The role of ice-algae as the ultimate source of lipids in overwintering pollock and cod needs to be evaluated [see for example Leu et al. (2011)]. Given the likely climatic changes in sea ice extent, the impact of their loss needs to be evaluated through appropriate modelling of the flow of energy densities if possible.
9. The high secondary peak in phytoplankton production output by the NPZD-FEAST model needs to be verified and/or explained. Some collaboration with PICES Continuous Plankton Recorder (Batten and Bychkov 2014) may be helpful to obtain additional empirical data for the area or to set up additional routes to provide information on relative planktonic composition and timing at low cost.
10. The EBS Ecopath with Ecosim (EwE) model should be developed to enable multi-model ensemble approaches. This model is also the most comprehensive in terms of higher trophic levels and may provide insights into the cascading, bottom-up ecosystem effects of changes to the recruitment of pollock.
11. Better communication and enhanced collaboration with some other programs will benefit the RPA greatly. These include MACE and the stock assessment team dealing with Pacific cod and arrowtooth flounder. MACE should be encouraged to apply some of their innovative sampling tools in the survey where resources allow, including cam-trawl and new broadband sonars which are capable of providing extremely high resolution data. Short term resources should be provided to MACE to develop acoustical analysis procedures that will lead to savings in staff time (acoustic analysis) in the long run.
12. International collaboration should be encouraged where possible, particularly with Russian and possible Japanese interests in the fishery. There are opportunities to engage with

European ecosystem modelling efforts through MAREFRAME (see http://www.mareframe-fp7.org/).

13. The future effects of climate change in terms of specific potential scenarios should be investigated. These scenarios start with the clear indication that ice cover will be reduced, but it is not clear from the presentations given what the net effect that will have on ocean productivity and in particular on the type of production (e.g. loss of sea-ice algae) and its effects on the massive pollock fishery. The RPA is the best equipped group to answer these issues and this reviewer would recommend that resources continue to be allocated to it to plan for potentially large changes in the years ahead.

Appendix **1: Bibliography of materials, including those provided for the review.**

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Appendix 2: A copy of the CIE Statement of Work

Review of Fisheries Recruitment Processes Applied Research in Support of Ecosystem Based Fishery Management of the Bering Sea Ecosystem

Scope of Work and CIE Process: The National Marine Fisheries Service (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Technical Representative (COTR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: We request an independent CIE review of the ecosystem and fisheries recruitment processes applied research conducted at the NMFS's Alaska Fisheries Science Center (AFSC). Ecosystem and fisheries research has been conducted by various programs within the AFSC for over 30 years. Recently several of these programs came together to form the Recruitment Processes Alliance (RPA), which joins expertise, merges effort, and facilitates scientific exchange in the study of Arctic and North Pacific ecosystem functioning. The RPA, comprised of the Recruitment Processes program (the Ecosystems and Fisheries Oceanography Coordinated Investigations or EcoFOCI), the Ecosystem Monitoring and Assessment (EMA) program (the Bering Arctic-Subarctic Integrated Survey or BASIS), the Marine Acoustics and Conservation Engineering (MACE) program, the Resource Ecology and Ecosystems Modeling (REEM) program, and the Resource Energetics and Costal Assessment (RECA) program, as well as the members of the EcoFOCI Program that reside at the Pacific Marine Environmental Laboratory (PMEL). This effort is a unique collaboration among NMFS programs within the AFSC and across-line offices (National Marine Fisheries Service and Oceanic and Atmospheric) with a primary goal to provide mechanistic understanding of the factors that influence recruitment of walleye pollock, Pacific cod, arrowtooth flounder, Chinook salmon and chum salmon, focusing on factors influencing the first year of ocean life. To accomplish this, seasonal (spring, summer, autumn) field surveys and process-oriented research are conducted to inform single-species, multi-species, and biophysical ecosystem models. Survey methods rely on gridded net tows and selected use of acoustics to collect target species, with concurrent oceanographic and environmental sampling to estimate biological and physical oceanographic structuring forces. For this review, an impartial evaluation of the joint, RPA fisheries-oceanographic research of the Eastern Bering Sea will be conducted to evaluate the survey methodology and analytical approaches used to estimate relative abundance, distribution, biomass, and physiological condition of target species, the biophysical environmental variables thought to structure recruitment of target species, and the incorporation of observed variables into ecosystem forecast models, Integrated Ecosystem Assessments (IEAs), and Ecosystem Based Fishery Management (EBFM) practices. The terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Review:

Four CIE experts shall participate in a panel peer review in accordance with the SoW and ToRs herein. The review panel shall have the combined expertise and working knowledge in (1) recruitment processes surveys and design including fisheries-oceanographic plankton and trawl survey design, operation, sampling and analysis; (2) familiarity with ocean ecology of early life stages of groundfish and salmonid species, (3) field methods, including acoustics for process studies, and spatial sampling and analysis of distribution and abundance of young fish; (4) experience in Ecosystem Based Fishery management and/or Integrated Ecosystem Assessment; (5) climate-coupled single-species, multi-species, and biophysical models. Each CIE reviewer is requested to provide a separate and independent evaluation. The CIE reviewer's duties shall include (1) conducting pre-review preparations with document review; (2) participation in panel review meeting; and (3) completion of a CIE independent peer review report in accordance with the ToR and the Schedule of Milestones and Deliverables. The agenda for the Panel review meeting will be provided to reviewers along with background materials two weeks prior to the panel meeting. Each CIE reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Location/Date of Peer Review: Four CIE experts shall participate during a panel review meeting scheduled at the **AFSC in Seattle, Washington** to be held during the dates of **July 21-24, 2015.**

Statement of Tasks: Each CIE expert shall complete the following tasks in accordance with the SoW, ToRs and Schedule of Milestones and Deliverables specified herein.

Prior to the Peer Review: Upon completion of the CIE expert selection by the CIE Steering committee, the CIE shall provide the CIE expert information (name, affiliation, and contact details) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to each CIE expert. The NMFS Project Contact is responsible for providing the CIE experts with the background documents, reports, foreign national security clearance, and information concerning other pertinent information. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

Foreign National Security Clearance: When CIE experts participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE experts who are non-US citizens. For this reason, the CIE experts shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website:
http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration-system.html

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to each CIE expert all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance with the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

Panel Review: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs. Modifications to the SoW and ToR cannot be made during the peer review, and any SoW or ToR modification prior to the peer review shall be approved by the COR and CIE Lead Coordinator. Each CIE expert shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their tasks shall be focused on the ToRs as specified in the contract SoW.

The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer **shall complete** the independent peer review addressing each ToR as described in Annex 2.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables.**

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review;
2) Participate during the panel review meeting in **Seattle, Washington** during **21-24 July 2015**, and conduct an independent peer review in accordance with the ToRs (**Annex 2**);
3) No later than **7 August 2015**, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to mshivlani@ntvifederal.com, and to Dr. David Die, CIE Regional Coordinator, via email to ddie@rsmas@miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

Schedule of Milestones and Deliverables: CIE **shall complete** the tasks and deliverables described in this SoW in accordance with the following schedule.

29 June 2015	CIE sends the reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
6 July 2015	NMFS Project Contact sends the CIE Reviewers the pre-review documents
21-24 July 2015	Each reviewer participates and conducts an independent peer review during the panel review meeting
7 August 2015	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
21 August 2015	CIE submits the CIE independent peer review reports to the COTR
28 August 2015	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: This "Time and Materials" task order may require an update or modification due to possible changes to the terms of reference or schedule of milestones resulting from the fishery management decision process of the NOAA Leadership, Fishery Management Council, and the Council's SSC advisory committee. A request to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent changes. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on changes. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToR within the SoW as long as the role and ability of the CIE experts to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW and ToRs. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (CIE independent peer review reports) to the COR (Allen Shimada, via allen.shimada@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards: (1) the CIE reports shall have the format and content in accordance with **Annex 1**, (2) the CIE reports shall address each ToR as specified in **Annex 2,** (3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon notification of acceptance by the COR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COR. The COR will distribute the approved CIE reports to the NMFS Project Contact and regional Center Director.

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Appendix 4: Participants **in the RPA review.**

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Kelly Kearney, University of Washington
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